

FATE FY2009: Integrating Ocean Climate Indices into Pacific Salmon Stock Assessments

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Abstract

Ocean climate and ecosystem variability is considered a main determinant of Pacific salmon recruitment. Short-lead (1-year) forecasts of abundance are used to set allowable harvest for numerous West Coast salmon stocks, but only one stock assessment (Oregon coast natural [OCN] coho salmon) incorporates ocean climate indicators. Historically, only physical climate indicators have been used to explain recruitment variation, but recent sampling by NOAA/NWFSC scientists have led to a number of biological ecosystem indicators, some of which show strong short-term correlations with salmon ocean survival. We propose to evaluate the suitability of these indices for improving short-lead stock forecasts, to use management strategy evaluation (MSE) techniques to evaluate their utility in improving harvest management, and to work with the management community toward incorporating climate indices into assessments for several salmon stocks.

Background

Numerous studies suggest that growth and survival of salmon during their early ocean life history phase is dependent upon ocean conditions (Nickelson 1986, Pearcy 1992, Cole 2000, Kareiva et al. 2000, Hobday and Boehlert 2001; Peterson and Schwing 2003, Beamish et al. 2004, Mueter et al. 2005, Pyper et al. 2005). Among research and data needs for harvest management documented by the Pacific Fishery Management Council (PFMC 2000), relationships with ocean productivity and climate are prominent. That report noted that rockfish growth and recruitment, salmon survival, and abundance of pelagic species all respond to changes in ocean condition, and that year-to-year patterns in production are similar across species groups. They conclude (p. 3) that “These holistic resource responses need to be assessed and incorporated into the management process.” Clearly, ecosystem responses to climate variation translate up the food web into fishery production, and efforts to understand, measure, and predict those relationships can improve harvest management.

The California Current is a highly-productive ecosystem that supports a high biomass of commercially-exploited fish species. Regular observations of the physical and biological oceanography of the California Current have been made from 1949 to present, chiefly by the CalCOFI program off southern and central California. During this 50+ year period, ocean conditions transitioned from a highly-productive “cool regime” from the late 1940s to 1977, to a “warm regime” of reduced productivity from 1977-1998, and back to a productive “cool regime” from at least 1999 through 2002 (Peterson and Schwing 2003). The past several years have been perhaps the most variable of the 50 year time series: the largest El Niño of the

century occurred in 1997-98 (McPhaden 1999) and this was followed by the largest La Niña in 1999 (Schwing et al. 2002), and another (albeit weaker) El Niño in 2002-2003. In 2005, an anomalous delay of summer upwelling had widespread biological effects across all trophic levels. This event was among the leading causes of widespread West Coast salmon stock failures in 2007 and 2008 (NWFSC 2008a,b), resulting in a nearly coast-wide closure of Chinook salmon fisheries in 2008.

Historically, there was little sampling of the Northern California Current (NCC) region off Oregon and Washington. Through funding from the National Marine Fisheries Service, the NOPP program and U.S. GLOBEC, the shelf waters off Newport Oregon have been sampled on a biweekly basis for the past twelve years (Peterson and Keister 2003), documenting seasonal and interannual changes in hydrography and zooplankton. Surveys of the hydrography, zooplankton, and juvenile salmon abundance have also been conducted along the WA and OR coasts in May, June and September as part of a study of habitat requirements of juvenile salmon (funded by the Bonneville Power Administration). These data have been used to develop a number of indicators useful for salmon forecasting (Peterson et al. 2006).

Short-lead (1-year) forecasts of abundance are used to set allowable harvest for West Coast salmon stocks (PFMC 2003). Forecasts typically are based on stock-recruit relationships and/or regressions of older age returns against younger-age (jack) returns within cohorts (“sibling regressions”). These techniques work well for many stocks, but fail when stock accounting is inaccurate or there are strong environmental effects on either maturation rates or mortality rates. To date, only one of these management forecasts (that for OCN coho salmon) incorporates ocean climate indicators (PFMC 2007). This is despite several efforts at developing climate-related predictors. Logerwell et al. (2003), Lawson et al. (2004), Scheuerell and Williams (2005), and Greene et al. (2005) provide physical descriptive models that forecast future returns for coho salmon, Snake River Spring Chinook salmon, and Skagit River fall Chinook salmon. In each case, physical features such as sea surface temperature, strength of upwelling, and the date of the spring transition were shown to be important attributes that correlated with returns of salmon.

These efforts are valuable first steps, but physical attributes that index potential salmon eventually fail as predictors. For example, past attempts to predict salmon returns based on upwelling indices worked well for a few years but then failed (Nickelson 1986, Pearcy 1992; cf. “UWI” line in Fig. 1). Our recent work demonstrates that the predictive skill of all long-term physical indicators for salmon varies with time (Fig. 1, Wainwright et al. 2007). This variation may be inherent to complex biological systems, resulting from the interaction of climate regime shifts with ecosystem phase transitions (e.g., Duffy-Anderson et al. 2005) due to the non-linear nature of ocean ecosystem dynamics (Hsieh et al. 2005). It may be that biological indicators may have more stable predictive power because they are more directly related to processes affecting growth and survival of juvenile salmon, but we only have very short biological data series to assess this.

Our proposed work will address these problems through a combination of statistical forecast modeling and management simulations in consultation with harvest managers.

Approach

Recent literature (e.g., Jennings 2005, Kaje & Huppert 2007) note the difficulties of evaluating the utility of indicators in harvest management, and note the importance of formal management strategy evaluation (MSE) techniques for demonstrating such utility. Kaje & Huppert (2007)

identify four criteria that must be met for forecasts based on environmental indices to be useful in harvest management: (1) Forecasts must match the management system in time and space, and must demonstrate direct causal linkages of indicators to stock response; (2) Forecasts must have sufficient skill in predicting the stock response; (3) Forecasts must lead to a clear management response (i.e. they must forecast a response variable that can be incorporated directly into management decisions); and (4) Forecasts must be valuable in terms of increasing economic value or improving achievement of conservation goals (i.e., they must be better than the existing management method). We will structure our approach around these four criteria.

The project will start (year 1) by focusing on an initial set of indicators (Table 1) which have been related to coastal salmon stocks (Peterson et al. 2006, Wainwright et al. 2007). These indicators include broad regional climate indicators (e.g. Pacific Decadal Oscillation and Oceanic Niño Index), local physical climate indicators (e.g., sea-surface temperature, upwelling, spring upwelling transition, river flow) at scales appropriate for specific salmon stocks, local measures of biological production and plankton community structure, and measures of abundance for major prey, competitors, and predators of the target stock. These indicators will be used to develop forecasts for a number of West Coast salmon stocks, with initial focus on the well-studied OPI hatchery coho, Snake River Spring/Summer Chinook, Columbia River Fall Chinook and Skagit River Fall Chinook salmon stocks, as those stocks provide the best potential for comparing our models with current management forecast models (PFMC 2003, 2007) and previous academic forecast methods (respectively: Logerwell et al. 2003, Scheuerell and Williams 2005, Greene et al. 2005). In this project, we will explore a number of multivariate forecasting techniques using modern quasi-parametric regression

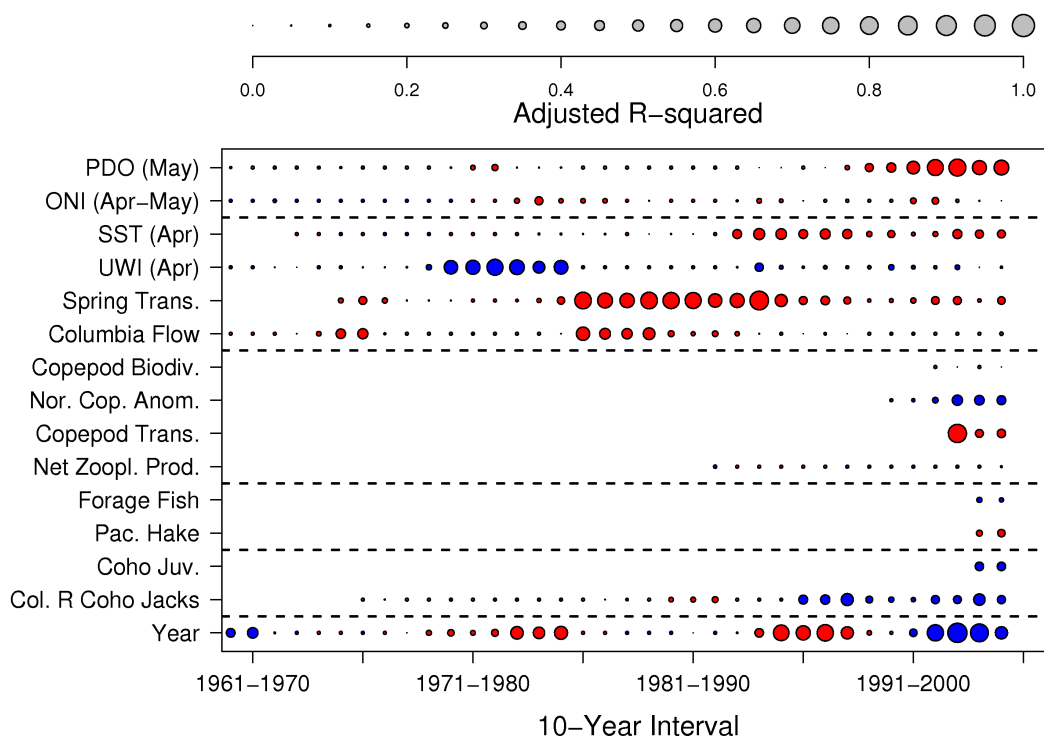


Figure 1: Patterns of temporal variation of statistical relationships (measured as adjusted R^2) for 15 indicator variables used to explain marine survival of Oregon Production Index (OPI) region hatchery coho salmon. Predictive regressions for each predictor were fit to 10-year moving data intervals. Symbol size indicates strength of the relationship; blue indicates a positive slope, red indicates a negative slope. Indicator variables are described in Table 1. From Wainwright et al. (2007).

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Table 1. Data series included in initial analysis.

<i>Data Series</i>	<i>Years</i>	<i>Source</i>
Pacific Decadal Oscillation (PDO)	1900-2006	http://jisao.washington.edu
Oceanic Niño Index (ONI)	1950-2006	ftp://ftp.cpc.ncep.noaa.gov
Sea Surface Temperature at Charleston, OR (SST)	1966-2006	http://opendap.co-ops.nos.noaa.gov
Upwelling Index, 45°N (UWI)	1946-2006	ftp://orpheus.pfeg.noaa.gov
Spring Transition, day of year	1964-2004	M. Litz, NOAA/NWFSC,
Columbia River Flow at Bonneville	1960-2006	http://www.nwd-wc.usace.army.mil
Copepod Biodiversity	1996-2006	W. Peterson, NOAA/NWFSC
Northern Copepod Anomaly	1969-2005	W. Peterson, NOAA/NWFSC
Copepod Spring Transition	1996-2005	W. Peterson, NOAA/NWFSC
Net Zooplankton Production Index	1980-2006	J. Ruzicka, NOAA/NWFSC
Forage Fish Abundance	1998-2005	R. Emmett, NOAA/NWFSC
Pacific Hake Abundance	1998-2005	R. Emmett, NOAA/NWFSC
Ocean Yearling Coho Index	1998-2005	C. Morgan, Oregon State University
Columbia River Coho Jack Index	1970-2006	PFMC (2007)

techniques such as generalized additive models (GAMs) and artificial neural network (ANN) models, that have been shown to perform better than parametric models for environment-recruitment problems (Megrey et al. 2005). We will also explore models that are adaptive, in the sense of emphasizing different indicator variables under different climate regimes or ecosystem phases, further developing work initiated by Wainwright et al. (2007).

During in the first project year, we will hold a workshop to present the initial forecasts developed and design the management strategy evaluation simulations. At this workshop, we will select indices to use, revise the initial list of focal stocks, and design the management scenarios to include in MSE simulations. Representatives from PFMC salmon-related committees as well as stock management scientists from state, tribal, and federal agencies will be invited to the workshop.

A key result of this workshop will be the design of the MSE analysis. Following selection of initial target indicators and stocks, we will evaluate the utility of indicator-based forecasts for each stock using the MSE approach as used, for example, by Punt et al. (2001). This involves a number of steps:

- 1) Identify management objectives and performance measures that quantify how well objectives are met. (For example, an objective might be to maximize economic return, with 50-year average net revenues to the fishery as the associated performance measure.)
- 2) Identify alternative harvest management strategies. In our case, these alternatives will be different methods of forecasting recruitment, including the current (status quo) method, a number of indicator-based forecasts, and other alternative methods selected during the workshop.
- 3) Develop a set of alternative operating models for the stock and fishery. These alternatives should identify and represent key uncertainties in the dynamic control of the system. Operating models will be designed to allow an evaluation of the robustness of management models to climate regime shifts and ecosystem phase transitions.

- 4) Simulate the future of the system under each management strategy and each operating model. This involves generating artificial climate indices, population production, and associated observation data (with observation error), applying the stock assessment methods (including fitting indicator-based forecast models to the data), simulating harvest in response to the assessments, and determining the resulting performance measures.
- 5) Summarize the results in terms of performance measures relative to status quo management methods.

As the project progresses (year 2), we will build upon the MSE experience to operationalize forecasts for the stocks where we could identify indicator-based forecasts that are superior to status quo methods. For these stocks, we will present our forecasts (in comparison to status quo forecasts) to harvest management committees (such as the PFMC Salmon Technical Team and the Columbia River Technical Advisory Committee) for their consideration. We will also expand our analyses to include newly developed indicators and/or to assess more stocks. Additional stocks for analysis will be chosen in consultation with the management communities on the basis of importance of the stocks and availability of stock data and local ecosystem indicators. There is little uniformity in data available for each stock, and physical or ecosystem variables affecting each stock can be expected to differ with location.

Benefits

This effort contributes to the FATE goal of improving stock assessments through the use of FATE indices. The project focus is on evaluating the utility of ecosystem condition indicators for management-related forecasts of Pacific salmon stocks. By examining the stability of predictive relationships, their short-term forecast skill, and their value in a harvest management context, this project will help the FATE program provide general information on the utility of climate and ecosystem indicators for harvest management. The work is also expected contribute directly to better short-term forecasts of salmon abundance for harvest management.

Deliverables

Year 1:

- Compiled database of physical and biological indicators for Pacific salmon recruitment.
- Summary of management workshop identifying target indices, focal stocks, and management scenarios to include in MSE simulations.
- Presentations to the salmon management community regarding progress on forecast model development.

Year 2:

- Presentations to management committees on results of MSE analysis.
- Updated indicators database.
- A published paper describing results of the management scenario analyses.
- Analytic toolbox needed for operational inclusion of climate indices in the PFMC salmon management system.
- Presentations to PFMC committees on final results of the project.

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